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Polyethylene Hip Resurfacing to Treat Arthritis and Severe Acetabular Insufficiency

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A B S T R A C T

Background: Hip dysplasia is the leading cause of hip arthritis in young adults. These patients often participate in active lifestyles that require a full and stable range of motion.
Methods: Between 2001 and 2011, 232 consecutive polyethylene resurfacing arthroplasties were performed in 201 patients with advanced arthritis from severe acetabular insufficiency due to dysplasia. All patients had Crowe II or III disease. Their mean age at surgery was 43 years. A 2-piece cementless acetabular resurfacing shell with dome screws and a highly cross-linked polyethylene liner were implanted to provide secure fixation, early weight bearing, and a stable hip. Additional structural bone grafts and/or fixation were not used. A cemented or cementless resurfacing prosthesis was used on the femur.
Results: During a mean follow-up of 10 years, 8 hips (3.5%) were converted to a total hip arthroplasty due to acetabular loosening (1), femoral neck fracture (2), femoral osteonecrosis (2), infection (2), or persistent pain (1), resulting in a mean survival of the resurfacing prostheses of 96% (95% confidence interval 89-98). There were no pending revisions and no dislocations. At 2 years postoperative, Harris Hip Scores improved from a preoperative mean of 55 to 97 and UCLA activity scores improved from 5 to 8.
Conclusion: Hip resurfacing using a 2-piece polyethylene acetabular component for advanced dysplasia has resulted in excellent function and implant survivorship with a low rate of complications at mid-term follow-up.

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There are substantial challenges in performing an implant arthroplasty for advanced arthritis in patients with a deficient acetabulum. This is particularly true in advanced dysplasia, when there are also torsional deformities of the femur with length and offset abnormalities. There may be soft tissue laxity and abductor insufficiency along with dysplasia. Obtaining secure component fixation and a stable articulation are the main surgical concerns. Most patients with severe dysplasia present at a young age, making bone preservation, function, and future revision options additional important goals [1–4].

Q3 Total hip arthroplasty (THA) allows the choice of the acetabular component to match the anatomy, as the femoral head size can be reduced from the natural size of 42-54 mm to 22-36 mm. The femoral component also can be adjusted for length and anteversion. Reducing the femoral head size comes with the penalty of reduced hip stability. Stemmed implants are intrusive to the femur [2,5–7]. Mobile bearing replacement procedures for enhanced stability such as dual mobility implants have been used commonly in recent years. If a modular metal liner allowing supplemental dome screw fixation is used, corrosion between the shell and metal bearing surface can occur [8,9]. A number of bone grafting techniques have been used to augment the deficient acetabulum, but none has produced outcomes as favorable as a primary THA [10,11].

Hip resurfacing provides high function and preserves bone. It can be performed in the presence of deformity or a blocked femoral canal [12]. Hip resurfacing patients have a more stable hip, better function during sports and activities, and a lower mortality compared to THA [13–20].

There is no uniform agreement about the advantages of hip resurfacing, which is a more technically challenging solution [21]. Metal-on-metal resurfacing implants with or without dysplasia screws can be difficult to insert and can be subjected to edge-loading conditions [22]. Also, metal resurfacing acetabular

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components are 1 piece. Milder dysplasia cases can be treated with primary implants by medialization of the acetabular component or accepting a more proximal position [13,17,23,24]. With severe dysplasia, such as Crowe II and III cases, the acetabular component will be partially uncovered [6,20,22]. Femoral osteotomy has been proposed to assist with correction of the femoral deformity, but it is desirable to avoid the complexity, possible complications, and weight-bearing restrictions of additional procedures [22,25]. A 2-piece resurfacing component with dome screws through the metal shell and a low profile can be used, even though this requires a large internal capacity to accept the larger natural-sized femoral head.

This prospective study addressed the following questions about hip resurfacing performed for a deficient acetabulum from dysplasia: (1) Can polyethylene hip resurfacing provide a stable and secure hip with a low failure rate? (2) What are the clinical scores, leg-length discrepancies, and radiographic results?, and (3) What is the polyethylene wear of retrievals?

Methods

The Institutional Review Board approved this single-center prospective study. Between 2001 and 2011, 232 consecutive polyethylene resurfacing arthroplasties were performed in 201 participants (77 men, 121 women, and 3 nonbinary gender). A single surgeon with many years of experience with polyethylene hip resurfacing performed all the procedures. All patients who met all of the following inclusion criteria were offered enrollment in the study: (1) pain and functional compromise that made a patient a candidate for THA, (2) femoral head diameter of 41-51 mm, (3) UCLA activity score goal of 6 or higher, (4) age ≤65 years, and (5) satisfactory bone quality and geometry defined as bone structure that could accommodate the resurfacing components without notching the femoral cortex or overreaming the acetabulum (medial wall thickness >5 mm). All patients had Kellgren-Lawrence stage 3 or 4 arthritis [26] and only Crowe II and III cases were included in this series [2]. The author performs hip resurfacing for other diagnoses such as osteoarthritis and osteonecrosis, but these patients are not part of this study. Five patients had prior pelvic osteotomies but still had Crowe II deformity.

The option of THA was discussed with all patients but those included in this study chose hip resurfacing. Exclusion criteria were the following: (1) poor femoral bone quality as indicated by femoral head cysts or osteonecrosis defects >2 cm, (2) below-normal bone density determined by plain radiograph, and (3) geometry that would not allow stable placement of the acetabular prosthesis with at least 5 mm of medial acetabular wall preservation and a post-operative femoral head:neck ratio of at least 1.29 without notching. It is possible to perform hip resurfacing procedures with less restrictive indications, but bone conservation was also one of the goals of this study. Bone quality was assessed qualitatively as within or below the normal range. The author did not use DEXA or magnetic resonance imaging scans to determine candidacy for hip resurfacing. Enrollment was not affected by the presence of abnormalities in the hip's center of rotation or femoral offset. The author also offered hip resurfacing to patients with other types of congenital and developmental deformities, such as protrusio.

The author also performed THA for 117 patients with hip dysplasia during the same time period. Patients with important symptoms in their feet or lower leg from torsional abnormality were treated with modular THA with or without femoral osteotomy. In the author's specialized practice, most patients preselect themselves for hip resurfacing. This practice referral pattern is also weighted toward acetabular dysplasia compared to other diagnoses. The author did not exclude patients based on leg-length discrepancy, contractures, or number of prior hip procedures.

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Fig. 1. This is a photograph of the acetabular shell used. There are 5 screw holes for 6.5-mm lag screws. There is an inferior cut and 3 locking tabs for the insert. The central impaction hole has 3 threads and the shell is 2-mm thick.

Implants

The acetabular component consisted of a 2-mm titanium shell with 1 mm of porous coating (FDA 510K 963101) (B-P Hemispherical Acetabular Component; Biocore9 LLC, Whippany, NJ). It is intended for uncemented use and has 5 screw holes and an inferior cut out for relief of the psoas tendon (Figs. 1 and 2). The screw holes are distributed evenly around the shell in order to avoid structural weakness and 6.5-mm lag screws with up to 10° of angulation were used. There is also a primary resurfacing shell appropriate for cases with better bone coverage that is similar but without screw holes. The shape of the component is based on the original Indiana Conservative Hip from 1973 (DePuy, Warsaw, IN) [27,28]. The highly cross-linked polyethylene liner is 4 mm thick and has 3 locking tabs to fit the shell. The polyethylene is formed from 1020 GUR (Ticona,

Fig. 2. This is a photograph of the highly cross-linked polyethylene acetabular insert.

Kieselbach, Germany) cross-linked with 7.5 mRad gamma irradiation and remelted at 155° (MediTech-Quadrant, Fort Wayne, IN). Sterilization was with ethylene oxide. The liner can be placed effectively in the shell typically with 2-3 mm of under-reaming. There is a central hole for the specialized impactor necessary to insert the thin acetabular shell. The shell deforms during impaction but placing the polyethylene liner reduces the amount of final shell deformation. With just a 2-mm shell, only a few threads are available for the impactor. A double-threaded impactor with reinforced driving platform supports the shell as it is driven in and protects against cross-threading of the shell on the impactor. A second impactor is necessary for the polyethylene, which can be seated even with deformation of the shell.

The femoral component is 3-mm thick, has a central stem, and can be placed with or without cement (New Jersey Conservative Femoral Resurfacing). There are no rotational or fixation fins on the femoral component. Both the femoral and acetabular components remain available (Biocore9, LLC).

Operative Technique

The femur was prepared in an anatomic fashion rather than flat-top fashion. The depth of the acetabular reaming was determined from preoperative templating and at the time of surgery. The anterior and posterior acetabular rims and medial wall were monitored continually. A drill hole was made at the superior edge of the fovea and a depth gauge was used to measure the socket depth. Reaming was continued until a secure position was achieved or the residual medial wall reached 5-6 mm. Complete coverage was not possible with the shallow and vertically inclined native dysplastic acetabulum. The manually tested stability of the component and degree of lateral uncovering were the deciding factors for the use of screws. The depth gauge was also used to measure from the edge of the component to the deepest point. The percentage of bone coverage was defined as the horizontal width of the acetabular component covered by the host bone divided by the width of the component. A temporary or permanent 5.5-mm headless screw could be placed through the central impactor hole to secure the position as the dome screws were placed. The anterior dome screw was then placed and is usually 30-45 mm in length. A second screw in the more superior location could be placed, if necessary, based on the amount of uncovering and manual stability testing. Occasionally, a smaller inferior or posterior screw was placed. Typically, there was more posterior bone in these dysplastic acetabula. The number of screws was based on manual testing of the security of acetabular component. Eighteen percent of participants required no screws, 70% required just 1 screw, 11% required 2 screws, and 1% required 3 screws. The goal acetabular inclination angle was 40°. Intraoperative imaging with an image intensifier was used to assure that the acceptable range of 30°-50° was achieved. The femoral anteversion was measured before bone preparation. Excess femoral anteversion was common and was compensated for by reducing the acetabular anteversion (Figs. 3 and 4). The goal for combined anteversion was ≤45°.

All procedures were performed using the superior approach. In this approach, the patient was side lying and the proximal exposure was through a limited split of the gluteus maximus. The entire gluteus medius was preserved. The hip capsule was identified and opened, a tenotomy of the piriformis and conjoined tendons was performed, specialized retractors were placed, and the hip was dislocated posteriorly. The capsule and tendons were repaired during the closure through drill holes to bone [29]. The size of the implanted components was determined by the size of the femoral neck. The acetabular component was 10-12 mm larger than the femoral neck. The acetabular preparation was done with under-reaming, as acetabular bone was limited and the thin shell was compressible. It is critical not to encroach on the femoral neck during preparation, as femoral neck fracture or femoral head necrosis can occur. The difference between the final femoral and acetabular reaming was 9 mm.

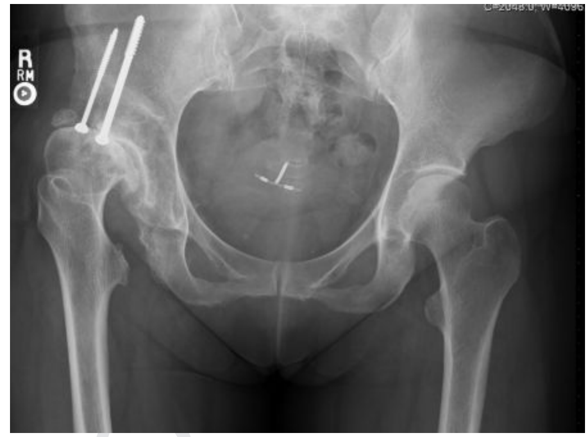

Fig. 3. This is an anteroposterior pelvic radiograph of a 35-year-old woman with a prior pelvic osteotomy. She presented with painful end-stage arthritis and 60° of combined anteversion.

Follow-Up

Immediate weight bearing was permitted and 55% of procedures were performed as a day-case surgery. Reoperation for any reason was considered a failure. All participants were followed in the outpatient clinic and the Harris Hip Score (HHS) [30], UCLA activity scale [31], and range of motion (ROM) were assessed by a therapist not involved in the participants' care. Radiologic assessment of the acetabular component was performed using the zones of DeLee and Charnley and of the femoral stem using the criteria of Amstutz et al; a score of 7 was considered significant [13,32]. An orthopedic surgeon not involved in the care of the participants performed the radiographic assessments. Standardized anteroposterior and 90° cross-table lateral radiographs were performed. The clinical measurements were made by the therapist using a goniometer.

Fig. 4. This anteroposterior radiograph of the pelvis shows the acetabular component medialized and the hip center moved inferiorly. The combined anteversion has been reduced to 45°.

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Statistical Analysis

The differences between the preoperative and postoperative scores (HHS, UCLA) and ROM were analyzed using the 2-tailed *t*-tests. The SPSS software package was used for the data analysis (version 14; SPSS Inc, Chicago, IL). Survival analysis was with the Kaplan-Meier survival plots with 95% confidence intervals.

Results

There were 77 men, 121 women, and 3 participants who did not identify as exclusively male or female; 31 participants underwent bilateral surgery. Their mean age at the time of surgery was 43 years (range 21-63) and all participated in sports and activities prior to surgery. The mean body mass index was 28 kg/m^2 (range 20-34). Their dysplasia was classified as Crowe type II (n = 171) and Crowe type III (n = 61). At a mean follow-up of 10 years (range 7-17), 3 participants had died of causes unrelated to the surgery and 3 had been lost to follow-up (3%). All other participants completed follow-up evaluations. No hips were converted intraoperatively to a THA. Eight hips (3.5%) were converted to THA at a mean of 4.1 years after initial surgery (range 4 months to 10 years). Conversions to THA were required because of femoral neck fracture (2), infection (2), osteonecrosis (2), and persistent unexplained pain (1). There was 1 revision of the resurfacing prosthesis for failure of osseointegration of the acetabular component. There were 3 instances of deep venous thrombosis (2 in calf veins and 1 in the femoral vein of the nonoperative limb) treated with oral anticoagulants for 6-12 weeks. There were no pulmonary emboli or cardiorespiratory complications. The mean blood loss was 240 cc (range 150-500). The mean operative time was 90 minutes (range 49-122).

There were no revisions for instability of the hip or loss of acetabular component fixation. The Kaplan-Meier cumulative survival at 10 years was 96.2% (95% CI 89-98). There were statistically significant postoperative improvements in clinical scores and radiologic data (Table 1). There was no change in acetabular component position at final follow-up from the immediate postoperative examination in any hip. The mean radiological leg-length discrepancy preoperatively was −11 mm. This means the operative limb was shorter than the nonoperative limb. The mean postoperative radiological discrepancy was 3 mm. The postoperative mean also included bilateral procedures. All but 3 participants had less leg-length discrepancy following surgery (Figs. 5 and 6).

The 2 femoral neck fractures and the 2 instances of osteonecrosis were treated by revision to stemmed femoral prostheses with retention of the acetabular prostheses and exchange of the polyethylene liners. Two deep infections were treated with 2-stage revisions. One acetabular-only revision was performed for acetabular component failure of osseointegration. This shell did not migrate and the screws remained intact, but there was pain and a progressive lucency. The revision to a new acetabular shell while maintaining the femoral resurfacing resulted in a healed acetabular component. One chronically painful prosthesis was revised to a THA, but the pain continued. There was 1 femoral palsy and 1 sciatic palsy with partial recovery and no dislocations. The mean amount of acetabular uncovering was 18 mm (10-30). The median acetabular component used was 58 mm (50-64). The median amount of acetabular shell boney coverage was 74% (range 67-85). The bone conservation, center of rotation, and leg-length measurements were compared to preoperative measurements and to the normal contralateral hip (if present). Two participants required more reaming than planned to achieve a stable prosthesis. The mean acetabular wall thickness postoperatively was 7 mm (range 1.5-15) compared to 18 mm (range 8-30) preoperatively. Femoral bone conservation (head:neck ratio) was 1.36 postoperatively versus 1.42 preoperatively ($P = .02$). No participant had compromise of the medial wall or femoral neck.

The radiographic analysis showed that 4 participants had Brooker grade 1 heterotopic ossification, 5 had grade 2, and none had grade 3. There was 1 hip each with an Amstutz femoral fixation score of 1 and 2 related to zones 1 and 2. There were 2 hips with a score of 7 from metaphyseal loosening in all 3 zones. Both these

Table 1
Mean Preoperative/Postoperative Clinical Scores and Radiological Measurements.

Outcome	Preoperative (Range)	Postoperative (Range)	*P*-Value
HHS	55 (40-77)	97 (78-100)	<.001
UCLA	5 (3-7)	8 (5-10)	<.001
Leg-length discrepancy (mm)	−11 (+5 to −30)	3 (−7 to +7)	<.001
Flexion (°)	92 (40-120)	126 (108-140)	<.001
Acetabular inclination (°)	65 (50-77)	39 (27-54)	<.001
Combined anteversion (°)	50 (0-60)	40 (30-50)	<.05

HHS, Harris Hip Score.

Fig. 5. This anteroposterior pelvis radiograph is of a 36-year-old woman who presented with end-stage arthritis and a deficient left acetabulum.

Fig. 6. This anteroposterior pelvis radiograph shows the modular polyethylene acetabular component secured by 1 screw; 80% of the acetabular shell is covered with native bone and the leg lengths are symmetric.

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hips had subsidence of the femoral component from osteonecrosis of the femoral head. One hip had a complete acetabular radiolucency (all zones) and met the criteria for acetabular loosening. No other acetabular components had radiolucencies. In summary, 2 femoral components had loosening from osteonecrosis and 1 acetabular component had failure of osseointegration. All 3 of these hips were revised. The combined anteversion was $\leq 45°$ in all participants.

Nine polyethylene retrieval specimens were available (8 revisions, 1 postmortem) and were assessed using a digital coordinate measuring machine (Mitutoyo America Corporation, Aurora, IL). The retrieval specimens obtained at revision or postmortem at periods of 3, 5, 7, 8, 9, 9, 10, 11, and 12 years post-resurfacing showed a mean wear rate of 0.05 mm/y (range 0.03-0.07) (Table 2). There was no internal or rim cracking, scratching, burnishing, or delamination, and the original machining marks were visible on 7 of the 9. Two liners showed signs of polyethylene creep into the empty screw holes.

Discussion

Hip dysplasia is the leading cause of hip arthritis in young adults. Hip dysplasia patients often participate in active lifestyles that require a full and stable ROM. THA and hip resurfacing revision rates have been higher when dysplasia is present compared to osteoarthritis [5,6,25]. Also, dysplasia patients with THA can have a subtle limp and reduced stride length [4].

Revision of a THA can be challenging [1,27]. The use of a 2-piece, metal-backed resurfacing acetabular component with dome screws and a highly cross-linked polyethylene liner has resulted in excellent survivorship, a low complication rate, and limited polyethylene wear. There were improvements in the HHS, UCLA activity scores, and ROM. Revisions, when necessary, were uncomplicated. Future revision options and hip stability were preserved along with the femoral head.

There are limitations to this work. All procedures were performed by a single surgeon with extensive experience in polyethylene hip resurfacing. Thus, results using this technique may not be achieved in other centers. An important limitation of hip resurfacing is the difficulty of the procedure, inviting errors. The follow-up is mid-term, but this is consistent with many other studies. Longer term follow-up could change the conclusions [2,3,5–7,13,14,17,22,25]. It would be helpful to have a paired bilateral study with 1 side a hip resurfacing procedure and 1 side a THA to determine which procedure a patient finds most useful. A control group was not part of this study. Patients presenting to the author often preselected in favor of resurfacing and this is considered a limitation of the work.

Approximately 70% boney coverage of the acetabular component was sufficient for achieving component stability with dome screws alone (without bone grafts or other fixation) [2,6]. It is not known whether less coverage would be enough, but others have also found that 70% is sufficient. The results of this study are helpful, but do not completely determine coverage limits for a thin cementless acetabular shell; however, this was not an objective of this study.

Highly cross-linked polyethylene may be more tolerant of increased acetabular inclination compared to metal-on-metal resurfacing components [14,27,33]. Highly cross-linked polyethylene has the necessary progressive resistance to wear, even the thin larger diameters used in this study [34]. The shell of the 2-piece acetabular component was visualized fully during impaction using a centrally fixed impactor, in contrast to metal 1-piece shells, which require a complex rim-holding, vision-occluding impactor. Also, the availability of up to 5 screw holes assisted in securing fixation. It is not known how many screws are needed and, in many patients, screws are not necessary. The flexible shell was placed with under-reaming to preserve bone, which allowed effective insertion of the flexible polyethylene liner. There is deformation of the thin shell with implantation. However, unlike metal shells, there was no identified difficulty from shell deformation and this is the subject of future work.

The resurfacing procedure was nuanced in deciding both the orientation and depth of bone preparation. The presenting increased femoral anteversion was addressed by reducing the anteversion of the resurfacing components. Stability and impingement have been concerns with reducing acetabular anteversion. Nevertheless, all shells remained secure and stable with just 1 instance of failure of osseointegration. Failure by femoral acetabular impingement did not occur in this study but is always a concern in resurfacing procedures. Bone grafts and femoral osteotomies either for shortening or to reduce femoral anteversion were not used in this study but have been used successfully in other works [22,25]. Such measures add complexity and can increase the recovery time.

Hip resurfacing using a highly cross-linked acetabular component has been quite successful for treating several diagnoses and avoids the concerns of a metal-on-metal articulation [21]. The polyethylene bearing surface can be changed independently if necessary but, to date, no cross-linked polyethylene bearing has shown substantial wear either clinically or in wear determination studies [14,27,33,34].

Favorable reports for treating dysplasia cases with metal-on-metal hip resurfacing with or without the use of dysplasia components have come from specialized centers and from surgeon implant designers [13,22]. Most FDA-approved metal-on-metal resurfacing components have been withdrawn from the US market due to concerns about adverse reactions to metal wear debris [21,35–37]. Smaller metal-on-metal (<48 mm) hip resurfacing components are not marketed for resurfacing in the United States.

Conclusion

Hip resurfacing with a 2-piece acetabular component with highly cross-linked polyethylene provided a secure, stable, and highly functional hip in young and active patients with severe acetabular insufficiency due to dysplasia.

Acknowledgment

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Table 2
Analysis of 9 Retrieved Components.

Retrieval No.	Years Postoperative	Wear Rate (mg/mc)	Volumetric Wear (mm^3/mc)	Linear Wear (mm/y)
1	3	8.8	9.4	0.005
2	5	14.2	15.1	0.007
3	7	12.8	13.6	0.007
4	8	11.7	12.5	0.006
5	9	15.9	17.1	0.007
6	9	9.1	9.9	0.004
7	10	10.2	11.6	0.005
8	11	13.4	14.3	0.007
9	12	7.7	9.1	0.003

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References

[1] Argenson JN, Flecher X, Parratte S, Aubaniac JM. Anatomy of the dysplastic hip and consequences for total hip arthroplasty. Clin Orthop Relat Res 2007;465:40–5.
[2] Crowe JF, Mani VJ, Ranawat CS. Total hip replacement in congenital dislocation and dysplasia of the hip. J Bone Joint Surg Am 1979;61:15–23.
[3] Overgaard S, Petersen A, Havelin L, Furnes O, Herberts P, Kärrholm J, et al. The prognosis of total hip arthroplasty (THA) in patients younger than 50 years of age: results of 14,610 Primary THA. J Bone Joint Surg Br 2011;93(Suppl. II):87.
[4] Romanò CL, Frigo C, Randell G, Pedotti A. Analysis of the gait of adults who had residua of congenital dysplasia of the hip. J Bone Joint Surg Am 1996;78:1468–79.
[5] Engesaeter LB, Furnes O, Havelin LI. Developmental dysplasia of the hip—good results of later total hip arthroplasty: 7135 primary total hip arthroplasties after developmental dysplasia of the hip compared with 59774 total hip arthroplasties in idiopathic coxarthrosis followed for 0 to 15 years in the Norwegian Arthroplasty Register. J Arthroplasty 2008;23:235–40.
[6] Garvin KL, Bowen MK, Salvati EA, Ranawat CS. Long-term results of total hip arthroplasty in congenital dislocation and dysplasia of the hip. A follow-up note. J Bone Joint Surg Am 1991;73:1348–54.
[7] Stans AA, Pagnano MW, Shaughnessy WJ, Hanssen AD. Results of total hip arthroplasty for Crowe Type III developmental hip dysplasia. Clin Orthop Relat Res 1998;348:149–57.
[8] Hothi HS, Ilo K, Whittaker RK, Eskelinen A, Skinner JA, Hart AJ. Corrosion of metal modular cup liners. J Arthroplasty 2015;30:1652–6.
[9] Lachiewicz PF, Watters TS. The use of dual-mobility components in total hip arthroplasty. J Am Acad Orthop Surg 2012;20:481–6.
[10] Kobayashi S, Saito N, Nawata M, Horiuchi H, Iorio R, Takaoa IC. Total hip arthroplasty with bulk femoral head autograft for acetabular reconstruction in DDH. Surgical technique. J Bone Joint Surg Am 2004;86(Suppl. 1):11–7.
[11] Mulroy Jr RD, Harris WH. Failure of acetabular autogenous grafts in total hip arthroplasty. Increasing incidence: a follow-up note. J Bone Joint Surg Am 1990;72:1536–40.
[12] Mont MA, McGrath MS, Ulrich SD, Seyler TM, Marker DR, Delanois RE. Metal-on-metal total resurfacing hip arthroplasty in the presence of extra-articular deformities or implants. J Bone Joint Surg Am 2008;90(Suppl. 3):45–51.
[13] Amstutz HC, Antoniades JT, Le Duff MJ. Results of metal-on-metal hybrid resurfacing for Crowe type-I and type-II developmental dysplasia. J Bone Joint Surg Am 2007;89:339–46.
[14] Amstutz HC, Takamura KM, Ebramzadeh E, Le Duff MJ. Highly cross-linked polyethylene in hip resurfacing arthroplasty: long-term follow-up. Hip Int 2015;25:39–43.
[15] Barrack RL, Ruh EL, Berend ME, Della Valle CJ, Engh Jr CA, Parvizi J, et al. Do young active patients perceive advantages after surface replacement compared to cementless total hip arthroplasty? Clin Orthop Relat Res 2013;471:3803–13.
[16] Costa ML, Achten J, Parsons NR, Edlin RP, Foquest P, Prakash V, et al. Young Adult Hip Arthroplasty Team. Total hip arthroplasty versus resurfacing arthroplasty in the treatment of patients with arthritis of the hip joint; single centre parallel group, assessor blinded, randomised controlled trial. BMJ 2012;344:2147.
[17] Coulter G, Young DA, Dalziel RE, Shimmin AJ. Birmingham hip resurfacing at a mean of ten years: results from an independent centre. J Bone Joint Surg Br 2012;94:315–21.
[18] Haddad FS, Konan S, Tahmassebi J. A prospective comparative study of cementless total hip arthroplasty and hip resurfacing in patients under age 55 years: as ten-year follow-up. Bone Joint J 2015;97-B:617–22.
[19] Kendal A, Prieto-Alhambra D, Arden NK, Carr A, Judge A. Mortality rates at 10 years after metal-on-metal hip resurfacing compared with total hip replacement in England: retrospective cohort analysis of hospital episode statistics. BMJ 2013;347:f6549.
[20] McMinn DJ, Snell KI, Daniel J, Treacy RB, Pynsent PB, Riley RD. Mortality and implant revision rates of hip arthroplasty in patients with osteoarthritis: registry based cohort study. BMJ 2012;344:e3319.
[21] Dunbar MJ, Prasad V, Weerts B, Richardson G. Metal-on-metal hip surface replacement: the routine use is not justified. Bone Joint J 2014;96-B:117–21.
[22] McMinn DJ, Daniel J, Ziaee H, Pradhan C. Results of the Birmingham Hip Resurfacing dysplasia component in severe acetabular insufficiency: a six- to 9.6-year follow-up. J Bone Joint Surg Br 2008;90:715–23.
[23] Dorr LD, Tawakkol S, Moorthy M, Long W, Wan Z. Medial protrusio technique for placement of a porous-coated, hemispherical acetabular component without cement in a total hip arthroplasty in patients who have acetabular dysplasia. J Bone Joint Surg Am 1999;81:83–92.
[24] Kaneuji A, Sugimori T, Ichiseki T, Yamada FK, Matsumoto T. Minimum ten-year results of porous acetabular component for Crowe I to III hip dysplasia using an elevated hip center. J Arthroplasty 2009;24:187–94.
[25] Bernasek TL, Haidukewych GJ, Gustke KA, Hill O, Levering M. Total hip arthroplasty requiring subtrochanteric osteotomy for developmental hip dysplasia: 5- to 14-year results. J Arthroplasty 2007;22:145–50.
[26] Kellgren JH, Lawrence JS. Radiological assessment of osteo-arthrosis. Ann Rheum Dis 1957;16:494–502.
[27] Buechel Sr FF, Pappas MJ. A metal/ultrahigh-molecular-weight polyethylene cementless surface replacement. Semin Arthroplasty 2011;22:66–74.
[28] Capello WN, Ireland PH, Trammell TR, Eicher P. Conservative total hip arthroplasty: a procedure to conserve bone stock. Part I: analysis of sixty-six patients. Part II: analysis of failures. Clin Orthop Relat Res 1978;134:59–74.
[29] Amantullah DF, Masini MA, Roger DJ, Pagnano MW. Greater inadvertent muscle damage in direct anterior approach when compared with the direct superior approach for total hip arthroplasty. Bone Joint J 2016;98-B:1036–42.
[30] Harris WH. Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. J Bone Joint Surg Am 1969;51-A:737–55.
[31] Zahiri CA, Schmalzried TP, Szuszczewicz ES, Amstutz HC. Assessing activity in joint replacement. J Arthroplasty 1998;13:890–5.
[32] DeLee JG, Charnley J. Radiological demarcation of cemented sockets in total hip replacement. Clin Orthop Relat Res 1976;121:20–32.
[33] Pritchett JW. Hip resurfacing using highly cross-linked polyethylene: prospective study results at 8.5 years. J Arthroplasty 2016;31:2203–8.
[34] Pritchett JW. Very large diameter polymer acetabular liners show promising wear simulator results. J Long Term Eff Med Implants 2016;26:311–9.
[35] de Steiger RN, Hang JR, Miller LN, Graves SE, Davidson DC. Five-year results of the ASR XL acetabular system and the ASR hip resurfacing system: an analysis from the Australian Orthopaedic Association National Joint Replacement Registry. J Bone Joint Surg Am 2011;93:2287–93.
[36] Howie DW, Holubowycz OT, Callary SA. The wear rate of highly cross-linked polyethylene in total hip replacement is not increased by large articulations: a randomized controlled trial. J Bone Joint Surg Am 2016;98:1786–93.
[37] Smith AJ, Dieppe P, Howard PW, Blom AW. Failure rates of metal-on-metal hip resurfacings: analysis of data from the National Joint Registry for England and Wales. Lancet 2012;380:1759–66.

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